PERMAFROST MAPPING USING GRASS

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Knowledge of the spatial occurrence of permafrost is critical for hydrologic and engineering purposes. The site for our study is the Caribou–Poker Creeks Research Watershed, a 37–square–mile area near Fairbanks, Alaska. The monitoring of air, surface and subsurface ground temperatures since 1986 in this discontinuous permafrost upland taiga environment has provided ground truth data for proximal permafrost and non–permafrost underlain terrain. In our initial analysis, we found a significant correlation ($r^2 = 0.68$) between observed mean annual surface temperature and calculated equivalent latitude for each of the seven drill hole sites. Equivalent latitude is a theoretical index of direct solar radiation incident on a surface, which serves as a measure of thermal energy received at that point. The use of a GIS to provide a spatial distribution for the equivalent latitude index was an obvious next step in mapping permafrost. Arc–Info DLG files of elevation, soil and vegetation developed previously were translated and imported into GRASS.An equivalent latitude map was developed in GRASS using the equivalent latitude algorithm and an algorithm derived from the observed variations of mean annual air temperature with elevation within the watershed. Further development of our permafrost mapping approach will include the location of all temperature recording sites with a global positioning system (GPS) for entry into the GIS and the refining of mapping algorithms to reflect differing surface energy balance regimes within the soil and vegetation mapping units.

MAP DEVELOPMENT AND GIS PROCESSES USED

The data used in this project was translated from an Arc–Info database of the Caribou–Poker Creek Research Watershed developed under the supervision of Leslie Morrisey for NASA. The data was translated into a GRASS4.0 geographic information system database on a SUN Sparcstation 330 system. The data resolution is 30 meters. The projection used is universal transvers mercator.

The translated elevation map was used as input to create slope and aspect maps using the GRASS r.slope.aspect command. There appeared to be a few places where slope and aspect data were aberrant. These are visible in our final maps as small horizontal linear patterns. An attempt was made to smooth the linear data by using GRASS's smoothing filters, however we felt that the results were not worth the loss of data that occurred throughout the rest of the map after the filtering process.

To create the equivalent latitude map we input the following equation into GRASS's r.mapcalc command:

$$\text{equivalent latitude} = \sin^{-1}(\sin(\text{slope}) \cdot \cos(\text{aspect}) \cdot \cos(\text{actual latitude}) + \cos(\text{slope}) \cdot \sin(\text{actual latitude})).$$

GRASS's r.mapcalc command didn't have a sin function, so the derivative equation was used:

```
equivlat = atan((sin(@slope.rec) • cos(@aspect.values) •
cos(65.18288))+cos(@slope.rec) • sin(65.18288)) /
(sqrt(1-exp((sin(@slope.rec • cos(@aspect.values) •
cos(65.18288))+cos(@slope.rec) • sin(65.18288)),2)))
```

The r.mapcalc command processed this formula for each 30 meter data cell of our study area and output a map of the results for each data cell, an equivalent latitude map. The "@"–sign is required in GRASS to enable the use of the category value instead of the category number in each of the map layers used.

To create the mean annual surface temperature (MAST) map, a regression equation was developed using elevation, equivalent latitude and temperature data from data sites in the study area. R.mapcalc was run using this equation:

```
mast__actual = 21.704-0.003 • elevation-0.29 • equivlat.
```

Temperatures of inversion zones were then added to the MAST map using the GRASS command r.infer to extract the inversion zones from elevation and slope maps. Pocket inversion zones at elevations from 250–599 meters were assigned a MAST of −2.0°C and other inversion zones from 195–249 meters were assigned a MAST of −4.0°C.

Decision–making rules were developed that would define areas with underlying permafrost. We then used these rules in a script file with GRASS's r.infer command to create the permafrost map layer. The following is the inference rules table script file used to create a map predicting permafrost according to the predicted MAST map, elevation, slope and equivalent latitude:

```
IFMAP mast__plus104-10
    THENMAPHYP9(mast permafrost zone)
IFMAP elevation 195-249
    THENMAPHYP 10-4.6(inversion zone)
IFMAP elevation 250-599
    ANDIFMAP slope.rec0-5
    THENMAPHYP 11(pocket inversion zone)
IFMAP equivlat 67-90
    THENMAPHYP 12 (permafrost).
```

GRASS evaluates each data cell of the map layers named in this table (MAST, elevation, slope and equivalent latitude) and creates a new map layer in which the cell is placed into a category according to the "rules" of the table. In this case cells which fall into the following categories would be put into the permafrost category in the new map layer: MAST categories from −6°C to 0°C, elevation categories from 195−249 meters, elevation categories above 67°north latitude. (Notice that the category numbers into which these cells were placed were originally 9 through 10. These were later reclassified into category 2 while every other data cell in the new map was reclassified into category 1).

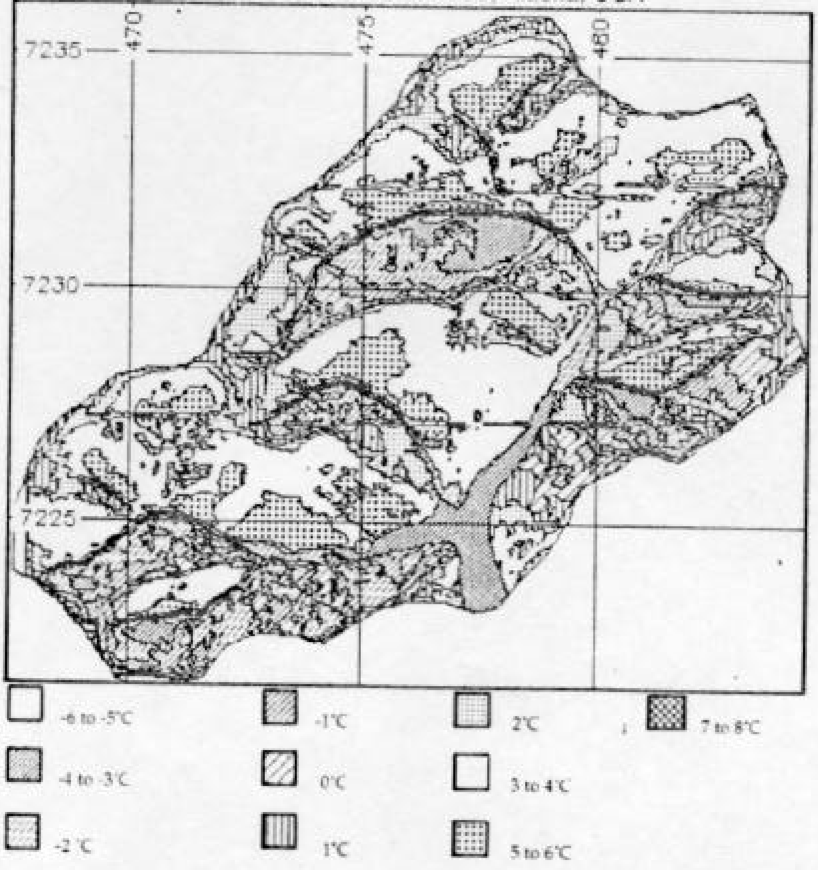
The predicted MAST and predicted permafrost maps shown in this study have areas of solid black coloration which are not defined in the legends. These are actually areas in which the patterns are so dense that the area outlines or patterns create the black effect.

FUTURE RESEARCH

Although the Caribou−Poker Research Watershed has been extensively studied by many researchers since it was first designated as a research area in the early 1970's, this study is the first systematic, longterm attempt to measure ground temperatures within the watershed with the objective of defining permafrost distribution relationships. The sites selected for ground temperature monitoring in Caribou−Poker Creeks Research Watershed were selected to sample a wide diversity of atmospheric, vegetative, and geologic characteristics, all of which influence ground temperature patterns and therefore the distribution of permafrost. The ground temperature information from this study combined with detailed information on site characteristics will permit the analysis of the complex distribution of permafrost in the watershed. The equipment needed to continually record air temperatures and near−surface ground temperatures at each of the borehole sites is expensive, and only recently have we been able to begin acquiring and installing this instrumentation. Three four channel data loggers were installed at three sites(T−1, K−25, and K−20A) in 1990. They are recording air temperature, temperature at two levels in the organic layer, and at the organic / mineral soil interface. In August 1991 a 12 channel logger with senors ranging from +150 cm above the mineral / organic soil interface to −140 cm below this surface, was installed at a valley bottom site near T−1A. These instruments, together with additional sensors designed to measure other components of the surface energy flux which will be installed as funding permits, will provide a more comprehensive analysis of permafrost distribution within the watershed.

Future plans also include a deep (100 to 200 m) bore hole in the valley bottom of Poker Creek is planned for the future. The intent is to penetrate the bottom of the permafrost in this area. The

Predicted Mean Annual Surface Temperature
Caribou-Poker Creek Research Watershed, Alaska, USA



borehole will be equipped with a multi-channel datalogger to continually record ground temperatures and complete surface energy budget instrumentation..

The spatial delineation of permafrost / non-permafrost boundaries will require a complex model which includes the terrain, vegetation, and energy balance components projected to a fine-mesh grid over the watershed. We plan to do this utilizing Geographic Infromation System (GIS) technology. The initial attempts will be done utilizing the more detailed air and surface temperature information obtained beginning in 1990, together with the subsurface temperature data which have been acquired beginning in 1986.

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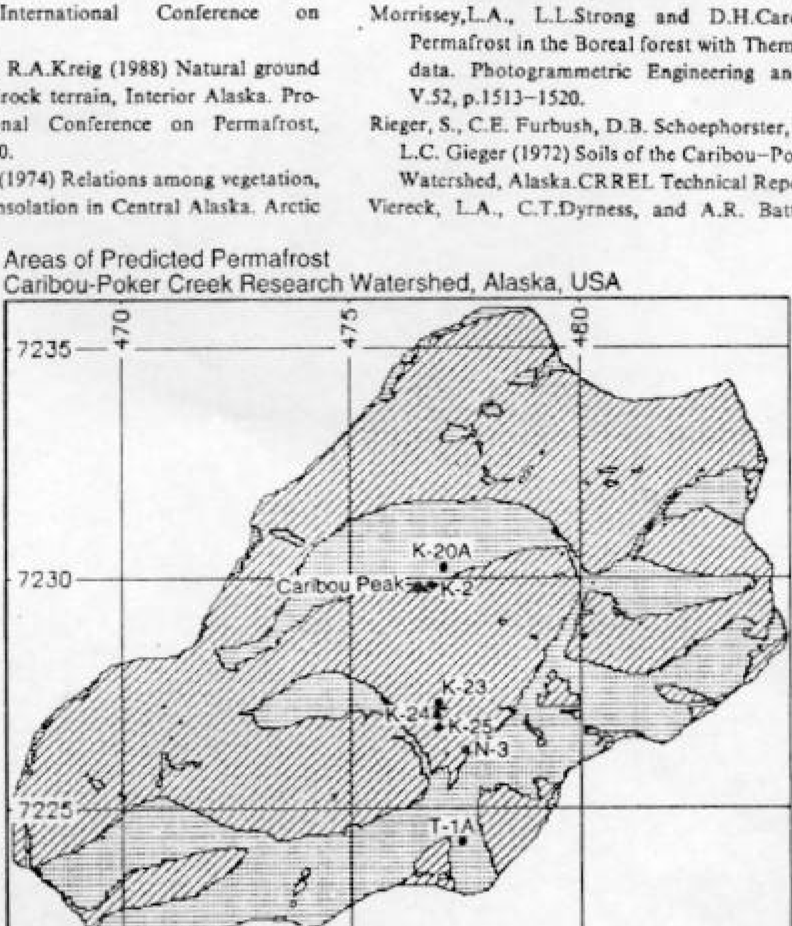
Areas of Predicted Permafrost
Caribou-Poker Creek Research Watershed, Alaska, USA



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